# HYDROLOGIC ANALYSIS WITHIN CALIFORNIA'S DAM SAFETY PROGRAM

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## Introduction

The topography and climate of California are extremely diverse, ranging from low elevations at the coast to the high altitudes of the Sierras, from less than 3 inches of annual rainfall in the southeast desert basins to over 120 inches on the extreme north coast. Drainage basins for dams vary in size from portions of an acre to thousands of square miles. Stream gages are sparse in most areas and are essentially nonexistent in the undeveloped areas. Accurate estimation of rare flood flows from recorded data is especially difficult due to the lack of basic site-specific flow data from which the flood producing potential of a drainage basin can be predicted. However, estimates of rare floods must be developed for all damsites to be used in evaluation of spillway capacities. To this end, precipitation records are employed in lieu of actual flow data. A method was developed by California's Division of Safety of Dams (DSOD) to estimate flood hydrographs for ungaged or poorly gaged watersheds for use in spillway evaluation.

## Outline of Method

DSOD requires that all dams within its jurisdiction be capable of adequately passing a selected design flood. A method has been devised by DSOD to determine the hydrologic adequacy of any spillway in California on a rational and consistent basis (DSOD, 1981).

The procedure can be divided into eight parts:

1. Assessment of the potential downstream hazard
2. Determination of appropriate storm return period
3. Development of precipitation
4. Development of synthetic unit hydrograph parameters
5. Development of loss rate parameters
6. Computation of the flood hydrograph
7. Routing of the flood hydrograph through the reservoir
8. Evaluation of the spillway adequacy

The following discussion will, elaborate on the basic concepts underlying these procedures, but will not present detailed design formulas or criteria.

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## Hazard Assessment

The hazard classification of any given dam is determined with respect to the dam's size and to the potential downstream damage due to failure of the structure. The classification is selected from a rating system that considers (1) reservoir capacity, (2) dam height, (3) estimated number of people that would be placed in peril and need to be evacuated in anticipation of dam failure, and (4) potential downstream property damage. Each factor is categorized as low, moderate, high or extreme. The method produces a composite numerical rating termed the Total Class Weight (TCW). The form, shown in Figure 1, is used as an aid to determine the TCW. With this system, small remote dams generally have a TCW of 2, while large urban dams might have a TCW of 36. The capacity of the reservoir and height of the dam are clearly defined. Estimated evacuation and potential downstream damage are uncertain and require an investigation of the potentially flooded area. This investigation includes estimating the population at risk, the possible loss of life, the physical property damage, the social consequences and the environmental impact. Through application to the many dams under its jurisdiction, DSOD has developed a coherent and uniform approach to conducting the damage investigations so that consistent total class weights are found.

DSOD does not allow the use of Economic Risk Analysis in the selection of a design flood for spillway evaluation. It is felt that the above procedure adequately addresses the issue of risk.

DAMAGE POTENTIAL CLASSIFICATION FOR

FLOOD ESTIMATE AND SPILLWAY ANALYSIS

Name of Dam __________________ Type of Dam ______________Dam No. __________

County _______________________ Located on _________________________________

Damage Potential Rating

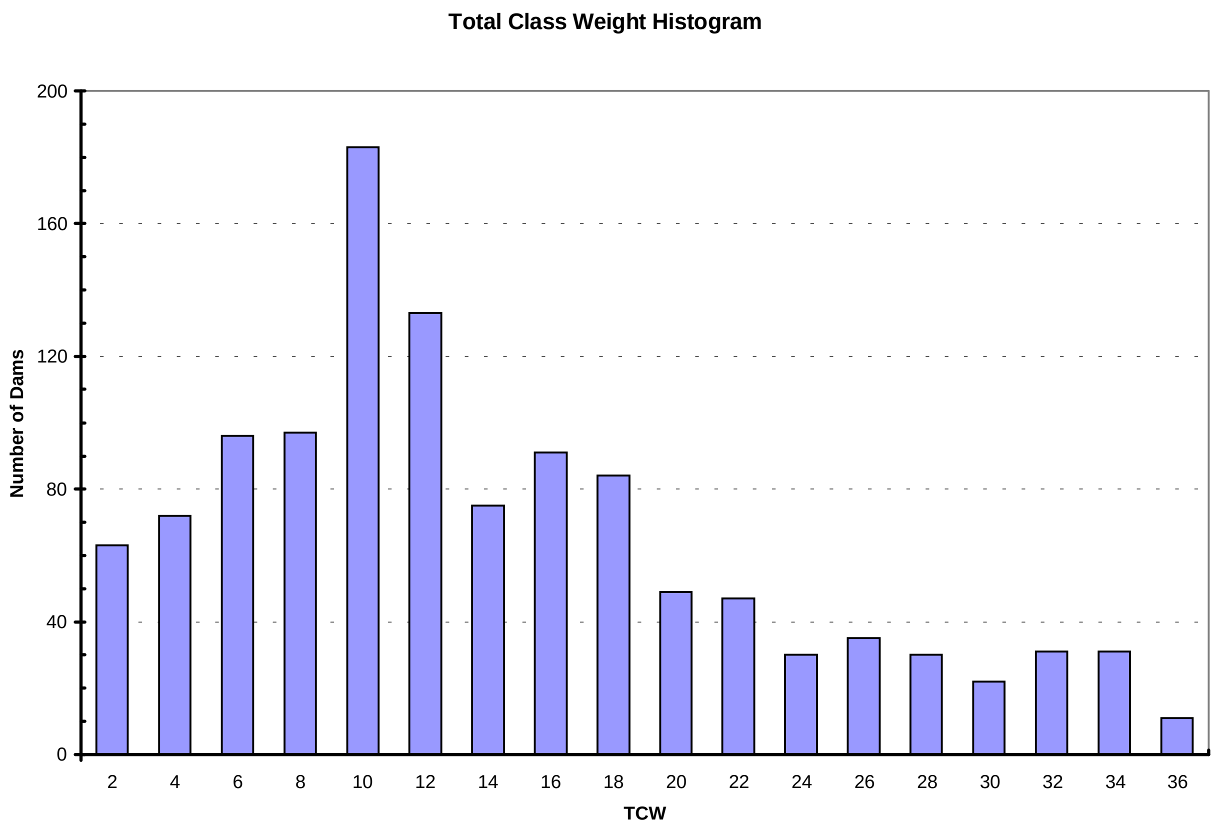
| | Extreme | High | Moderate | Low |
|---|---|---|---|---|
| Capacity __________ AF | 100,000 & Over | 1,000-99,999 | 100-999 | 15-99 |
| (circle weight) | 6 | 4 | 2 | 0 |
| Height ____________ Ft. | 150 & Over | 100-149 | 50-99 | 6-49 |
| (circle weight) | 6 | 4 | 2 | 0 |
| Estimated Evacuation ______ | 1,000 & Over | 100-999 | 1-99 | None |
| (circle weight) | 12 | 8 | 4 | 0 |
| Potential D/S Damage | High | Moderate | Low | None |
| (circle weight) | 12 | 8 | 4 | 0 |

Total Class Weight ________

Figure 1

## Precipitation

It is prudent to a allow a continuous range of design floods corresponding to the developed Total Class Weights. The minimum allowable design event required is a 1000 year storm which corresponds with a TCW of 4. The maximum event is a storm derived from the Probable Maximum Precipitation and is equated with a TCW of 30. The design event is interpolated between these limits at the computed TCW. Typically, probable maximum precipitation storms are required only for dams that impound 1000 acre-feet or more, are at least 50 feet high, would require an estimated evacuation of at least 1000 people, and have a damage potential of $25,000,000 or greater. However, most dams require a design storm falling between the 1000 year event and the probable maximum event. Figure 2 presents a histogram of TCW (as determined by DSOD) for all jurisdictional dams within California. As can be seen, less than 8 percent of all dams require a PMF.




If the TCW is 30 or greater, the design storm is the probable maximum precipitation (PMP) as determined by Hydrometeorological Report No. 36 (U.S. Weather Bureau, 1961) or Hydrometeorological Report No. 49 (National Weather Service, 1977), depending on geographical location. The estimated rainfall is determined directly for these reports.

If the TCW is less than 30, a statistical frequency estimate of the rainfall is chosen. It is assumed that extreme precipitation follows a Pearson Type III probability distribution, with a general skew of 1.3 for northern California and 1.5 for southern California.

The equation for precipitation is:

$$P_{ij} = M_i + k_j * S_i$$
$$= (1.0 + k_j * CV_i) * M_i$$

where:

$P_{ij}$ = extreme precipitation value
$M_i$ = average of extreme values
$S_i$ = standard deviation
$k_j$ = frequency factor
$CV_i$ = coefficient of variation

where:

subscript $_i$ denotes the event duration
subscript $_j$ denotes the return period

The appropriate coefficient of variation for the drainage basin is obtained from Bulletin 195 (DWR, 1976). This publication is a statistical compilation of observed rainfall data for both long-term and short-term durations from measuring stations throughout California. The mean rainfall values for various time durations are found from Bulletin 195 or from other available rainfall records for stations in the vicinity of the given basin. These means combined with the proper number of standard deviations give the precipitation estimates.

The number of standard deviations (k,) required for a 1000 year storm is 4.96 for northern California and 5.23 for southern California. The equivalent number of standard deviations for the PMP is obtained from a generalized contour plot relating this upper limit to geographical location. Using a nonlinear proration between these two points ($k_{1000}$,$TCW_{1000}$ and $k_{PMP}$,$TCW_{PMP}$), the k, for the given TCW is obtained. The corresponding return period is computed from the probability distribution.

The rainfall depth-duration values are estimated either by the PMP procedures or the above described statistical method. After adjustment for watershed area, the results are plotted on log-log scales and smoothed if necessary to obtain the depth-duration curve.

## Unit Hydrograph

Where no known reliable hydrographs exist, recourse is made to the computation of a synthetic unit hydrograph by Clark's method (Clark, 1945). Clark's unitgraph parameters are obtained from a generalized study of observed rainfall and runoff events, which related these parameters to drainage basin characteristics by regression analysis (DWR, 1971). The study is applicable to the State of California except that area south of the Tehachapi Mountain Divide and the area east of the Sierra Nevada Divide. The study was limited to drainage basins approximately 30 square miles or less in area, in recognition that approximately 80 percent of the dams under jurisdiction of the Division of Safety of Dams have drainage areas of less than this size. Most of the damsites for large reservoirs have been exploited in California, and dams that will be constructed in the future will, for the most part, be smaller in size and have relatively small drainage areas. Future dams with large drainage basins will require special investigation.

The regression equations from the generalized study relate the drainage basin characteristics of stream length, area, elevation, and ground cover to the time of concentration ($t_c$) and Clark's storage coefficient (R) for development of a basin-specific unit hydrograph. The study also presents guidelines for estimating loss rate parameters.

For coastal basins south of the Tehachapi Mountains, the unitgraph and loss rate parameters are obtained by the procedure given in the U. S. Army Corps of Engineers report entitled "Generalized Standard Project Rainflood Criteria-Southern California Coastal Streams", (Hydrologic Engineering Center, 1967).

Guidelines for southeastern California have been developed in a study (Mayer, 1987) similar to that for northern California. The region is subdivided into three subareas, with regression equations presented to develop unit hydrograph and loss rate parameters.

### Flood Hydrograph

The flood hydrograph is developed using the computer program HEC-1 (Hydrologic Engineering Center, 1981). The program obtains the flood hydrograph by convolution of the effective rainfall increments with Clark's unitgraph.

Rainfall increments are determined from the depth-duration curve at specified time intervals and are then arranged into a storm pattern which places the maximum value at the center of the storm duration with successively smaller values placed alternately on each side (approximating a bell-shaped distribution). In general, the total precipitation duration is taken to be 72 hours. If routing will not significantly affect the peak outflow, a shorter storm (e.g., 24 hours) can be considered since the peak inflow will be about the same in either case.

It is assumed that antecedent storms have saturated the drainage basin so that loss rates are fairly low. For each time interval, the losses from rainfall due to surface retention and infiltration are estimated by the exponential loss rate function within HEC-1. These losses are deducted from the distributed precipitation to produce excess rainfall values for each time interval. The general criteria is that the percent runoff should not be less than 70 when the mean annual precipitation (MAP) at the basin is greater than 25 inches and should not be less than 60 when the MAP is 25 inches or less.

If applicable, allowances for snowmelt, base flow in the basin, runoff from prior storms, import of water etc., are added to the storm runoff hydrograph to obtain the design flood hydrograph for the watershed.

### Flood Routing Through Reservoir

The design flood hydrograph is routed through the reservoir and spillway(s) to obtain the time-history of storage elevation, spillway discharge, tailwater elevation, etc. that describe passage of the flood through the reservoir. This is essentially a process of accounting for volumes of inflow, storage, and outflow throughout the duration of the flood. It is usually assumed that the reservoir is full at the beginning of the design flood. If there are several reservoirs in the watershed, the reservoir routing is repeated from the uppermost to the most downstream reservoir, in turn.

### Evaluating Spillway Capacity

New embankment dams must pass the spillway design flood with a minimum of 1.5 feet of residual freeboard above the maximum reservoir flood stage. Additional freeboard is required for severe wave conditions from wind effects. Residual freeboard requirements for new concrete dams are based on the ability of the abutments and foundation to resist damage from overpour. Existing embankment dams must pass the spillway design flood without overtopping.

## Refinements and Future Enhancements

It is the policy of DSOD to continually refine the developed methodology as new data becomes available and as the state-of-the-art advances. A reevaluation of the coefficients of variation, skew factors, and the appropriate probability distribution for precipitation is presently underway.

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